THE MICROSCOPY

OF

THE MORE COMMONLY OCCURRING STARCHES

BY

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Illustrated by 22 Original Microphotographs

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PREFACE

This little work embodies the results of an investigation carried out by the author as a research student in the Public Health Laboratory at the University of Glasgow while acting Professor of Forensic Medicine and Public Health there. The need for an accurate description and delineation of the commoner starch grains was brought prominently before the author's notice in teaching; scant information, and that not remarkable for accuracy, being furnished by the various text-books. The present work does not pretend to be exhaustive. Should its reception be encouraging, it may be further developed.

It is hoped that the book may prove of value to, amongst others, laboratory workers (teachers and students) in public health, analysts, brewers, and bakers.

Glasgow,
October 1, 1900.

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INTRODUCTION

It is not a little singular that, in spite of the importance from many points of view of an accurate delineation of the starches, very little has been done in this direction—in this country, at least — up to the present time. This is all the more remarkable when we bear in mind that starch grains have been noted, described, and figured, after a fashion, from the earliest days of the compound microscope. It was early observed that starch from different plants betrayed in many cases marked differences with regard to the size, shape, and structural markings of the individual grains, and the differences were, of course, illustrated by figures. These figures (with the exception of those traced by the aid of the camera lucida) never were much above the level of mere diagrams, and the main explanation, at least, may be put in two words, oft quoted by Sir William T. Gairdner, viz., the 'personal equation.'

I was greatly impressed by this fact as to the

'personal equation' during the past two summer sessions while watching my students making sketches for themselves of the various specimens shown under the microscope. In no two cases were these sketches similar in anything but the grosser details, and yet each conveyed to the mind of its delineator an impression, more or less accurate, as to what he or she considered to be the salient features of the specimen.*

With regard to this 'personal equation,' I draw no distinction between teacher and student. Any advantage on the teacher's side is simply that he knows what points ought to be brought out prominently, while the disadvantage is that his drawings are too apt to be copied and referred to as if they were free from any error of this kind.

Another fact which I have had brought prominently under my notice is that in most cases students prefer to go by the illustrations which appear in their text-books rather than take their information from the actual specimens. In my own department this has been specially noticeable with regard to starch grains on the one hand and fibres of all

* As an example of the foregoing I may quote one instance, where a student had made a sketch of several grains of Bermuda arrowroot starch without inserting the hilum. On my pointing out that it was important to note the position and shape of the hilum, the student, after looking at the specimen again, inserted a representation of the hilum near the narrow, instead of the broad, end of each grain. As a matter of fact, one or two of the starch grains in the 'field' shown *had* the hilum near the narrow end; but, as this is comparatively uncommon, the sketch was so far misleading.

kinds on the other. An example of this I shall quote later on.

The adaptation of the camera lucida to the microscope greatly facilitated a correct delineation of the outlines of microscopic bodies; but its use is limited to that and to the depicting of gross markings in the interior of such bodies. Even amongst persons accustomed to the use of the camera lucida different observers give very different 'renderings' of the same specimen; and there is here still the danger, almost the certainty, of the observer giving undue prominence by his pen to some parts of the specimen, with a corresponding failure to give proper value to the remainder. As an example of this I may refer to the figure of potato starch drawn with the camera lucida shown on p. 371 of Hassall on 'Food.' In this drawing the concentric lines in the interior of the grain are made far too prominent, while no attempt is made by shading to indicate that the surface of the grain is not flat, but slightly convex.

CHAPTER II

MICROPHOTOGRAPHIC METHODS

WITHIN comparatively recent years a powerful auxiliary in microscopic illustration, in the shape of photography, has been employed, and much good work has been done in this direction by Neuhauss in Germany, and Pringle, Bousfield, and Spitta in this country. The advent of isochromatic plates, extremely sensitive films, and rapid printing processes not dependent upon sunlight, have done much to facilitate such work; and it is not too much to say that microphotography* has in many departments completely revolutionized the art of microscopic illustration.

While, of course, photography applied to microscopic work has certain disadvantages, the advantages are so numerous and vital that wherever it can be employed it gives results, in skilled hands, immeasurably superior to those obtained by any other process or combination of processes. In the present book I have no intention of writing at length on microphotographic methods, but there are some points in connection with their application in

* I use the word microphotography in preference to photomicrography, as the meaning is equally clear, while the word is more euphonious.

the present investigation which are too important to be omitted. Having decided that microphotography alone would enable me to eliminate the sources of error which I have previously mentioned, I was brought face to face with the difficulty that the point at which microphotography is apt to fail is where there is a want of contrast in the objects under examination; and in the case of translucent, highly-refracting bodies like starch grains, this difficulty is very real indeed. In spite of this, I was able to obtain, by various modifications of the ordinary methods of microscopy, representations of starch grains which are perfectly true to nature as far as the details actually shown are concerned; and in many cases details quite invisible to the naked eye are brought out on the photographic plate.

With regard to the working details I need say very little. This is not a treatise on microphotography as an art, and it may suffice to mention that my results have all been obtained with a specially adapted camera and a microscope fitted with ordinary achromatic objectives and Abbé non-achromatic condenser, the source of light in every instance being an ordinary paraffin lamp with half-inch wick, the flame being used 'edge on,' and the microscope being in the horizontal position. No mirror was necessary, and the rays of light were parallelized by an aplanatic bull's-eye. A light filter was unnecessary owing to the source of illumination, and was not used. To obtain a perfectly flat, clear, and circumscribed 'field,' a No. 4 projection ocular was employed. The magnifica-

tions varied from 116 to 500 diameters, but 116 and 380 were those most commonly adopted.

In beginning this investigation I was handicapped by having no knowledge whatever of photographic methods, and any imperfections in my earlier prints are due to this fact. Under or over exposure, development, or printing are responsible in some cases for non-appearance or obliteration of detail. Notwithstanding this, I have included even my earliest results, as they show that even photography applied to microscopic work, while never telling anything but the truth, may yet fall short of telling the *whole* truth.

CHAPTER III

MEASUREMENT OF THE GRAINS

In any investigation into the microscopical appearances of starch grains it was clear to me that one of the fundamental and most important points was to obtain accurate **measurement** of the various grains. Here again microphotography was of great value, as by taking a negative of a micrometric scale magnified x times it served for measuring all starch grains under the same conditions of objective, ocular, and tube and camera lengths. From my previous experience of microscopic methods I had no hesitation in employing for this purpose the stage micrometer in preference to the micrometer eyepiece, and in adopting the micrometer scale, divided into parts of a millimetre, in preference to one divided into parts of an inch. Had I used the micrometer eyepiece it would have had one great advantage: viz., I could have photographed the divisions on the same negative and at the same time as the starch grains. There were, however, three drawbacks to this method, the first being that I could not have employed the projection ocular, the second that the divisions of the micrometer eyepiece were not sufficiently fine for my purpose, and the third that the divisions themselves would interfere with that

clear view of the whole 'field' of the microscope which I considered at least advantageous, if not absolutely necessary.

Having come to the conclusion that accurate measurement of the starch grains was an essential element in this investigation, I first exposed a plate with the view of getting a negative of a stage-micrometer divided into hundredths of a millimetre. With regard to the magnification, I had previously made experiments in order to find what appeared to me to be the most suitable camera length for the larger starch grains, by projecting images of these grains upon the focussing screen at varying distances, and the one fixed upon was adhered to throughout the investigation.* Here there was no want of contrast between the object to be photographed and its surroundings; and it is not very surprising that my first negative, with an exposure of five minutes, was a fairly good one, and gave prints which were perfectly satisfactory for measuring purposes. A print obtained from this negative is shown in Fig. 1. On measuring the lines on the print, I found that the magnification was, as nearly as possible, 116 diameters, and this was the magnification employed in most cases.

* I may mention that the microscope tube-length of 160 mm. remained unaltered throughout, and that the objectives employed were: for the lower magnifications, Reichert's No. 3; and for the higher (380 and over), Reichert's No. 7*a*.

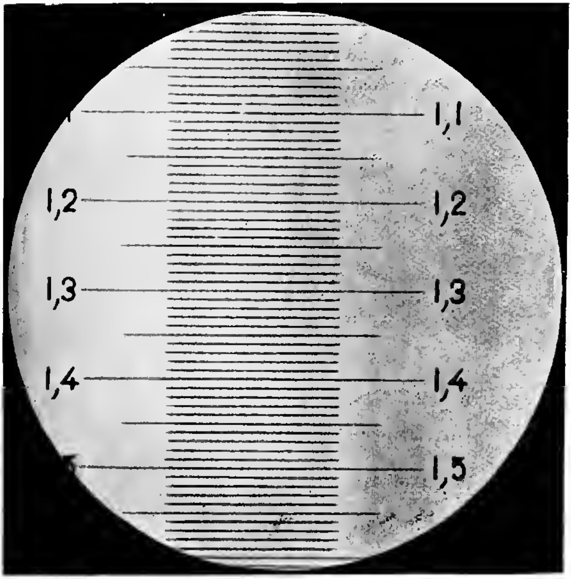

Fig. 1.—Micrometer Scale, ×116.

CHAPTER IV

POTATO STARCH

In turning my attention to the starches themselves, it occurred to me that, bearing in mind the difficulty of obtaining good photographs of objects so deficient in contrast as starch grains, it might be possible to obtain better results by employing dark ground illumination.* Adopting this method, therefore (other conditions being as when taking the negative of the micrometer scale), I took a negative of potato starch. Fig. 2 shows a print from this negative. It became evident to me very soon that, while in some respects negatives obtained in this way were of great value as far as outline was concerned, they would not readily show any very fine markings in the interior. On the whole, however, this print gives some valuable information. The translucency of the grains is well brought out, and also their uniformly rounded nature. The peculiar double grain, shown in the upper left-hand quadrant of the print, which is often present in this starch, the general shape and variation in size of the grains, and the convexity of the surface, are all apparent. It

* In all cases the descriptions apply to starch grains preserved in an aqueous medium.

will be noted, however, that, with the exception of a line transversely placed near the end of some of the grains, there is no indication of any internal differentiation of structure. The line mentioned, while it is in the situation of the hilum, does not represent what may be termed the normal appearance of the hilum of the potato-starch grain.

With regard to the points actually brought out by Fig. 2, I shall consider them seriatim.

1. Little need be said as to the **translucency** of the grains, as this is quite obvious to anyone who has ever examined potato starch microscopically, and is well shown in the figure.

2. The **rounded nature** of the grains is of some little importance, mainly as a point of comparison with other starches, to be described later, which show angular and faceted grains. Under no natural conditions does the grain of potato starch show any trace of angularity in its outline. While in some 'fields' of pure potato starch small angular particles are sometimes present, these latter are probably fragments only of original grains.

3. The **double grain** already referred to as shown in the print is of not infrequent occurrence in an average 'field' of this starch; that is to say, one or two such grains are occasionally present in such a 'field,' and are as characteristic of potato starch as the single grains.

4. As to the **shape** of the potato-starch grains, they are usually described as 'oyster-shaped.' What is meant by this I do not know, but if 'oyster-shell-shaped' is what is understood, then I say emphatically that this description is mis-

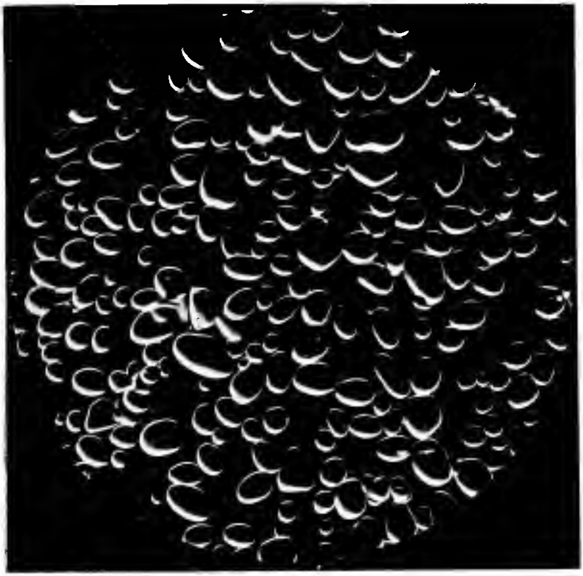

Fig. 2.—Potato Starch, ×116. (Dark Ground.)

leading. It will be quite apparent, on examining Figs. 2 and 3 carefully, that the term 'oyster-shell-shaped' could not be applied to even a single one of the grains present in the 'field,' although in other 'fields' some of the grains show an approximation to this shape. Unfortunately, the diversity in shape of the grains is so considerable as to render it well-nigh impossible to find a descriptive term which would apply to the majority of the grains, and I am not able to suggest such. It is evident, however, that the great majority of the grains are flattened, and have a **short and a long diameter**, and may roughly be termed **flattened ellipsoids.** In some cases, not by any means rare, the outline of the grain is almost that of a true ellipse, while divergence from this is chiefly in the form of narrowing of one end and broadening of the other. The longitudinal diameter may in all cases be represented by a **straight line**; this point is of importance in comparison with some of the other starches considered further on.* A few of the grains, **and these the smallest,** are almost perfectly spherical, and it may be said at once that it is impossible microscopically to distinguish such grains from the spherical grains of similar size found in, for example, rye, wheat, and barley (see pp. 22, 66, 74).

5. The **size** of the grain is of considerable importance. Even a momentary glance at the prints will show that this varies very much as between individual grains; but the average over

* In what I have said in this paragraph I refer entirely to the appearances shown in Fig. 2, without reference at present to the position of the hilum, etc.

the whole 'field' is (omitting the small, spherical, atypical grains) a little less than $\frac{1}{25}$ mm. in the long diameter, and about $\frac{1}{37}$ mm. in the short. Taking twenty of the largest grains in the field, the long diameter averages a little over $\frac{1}{20}$ mm., and the short a little less than $\frac{1}{25}$ mm. This absolute measurement will be found of great value in comparing the various grains as to size. It will be found that in different 'fields' the variation from the measurements just stated is comparatively slight, especially in the case of the larger grains, although the stage of growth of the tuber, and even the source of the potato, may increase this variation to some degree.

6. The **convexity of the surface** is well indicated, even in the smallest grains, by the gradual shading off of the light as the centre of the grain is neared. (The photograph was taken with **oblique** light, as well as on a dark ground.) It will be noted, too, that this shading off is perfectly uniform, a point of some interest with regard to differentiation of structure in the interior of the grain, and which will be referred to later.

7. As it was clear that dark ground illumination did not reveal the finer details of **internal structure**, I had to resort to transmitted light and endeavour to obtain a negative by its means. I soon found myself confronted by a formidable difficulty. It was comparatively easy to obtain a negative showing the outlines of the grains, but to obtain one which showed the concentric lines in the interior with sufficient intensity to be apparent on the print taken from the negative, without the background being blurred, was not

Fig. 3.—Potato Starch, ×116.

an easy matter; and various experiments in the direction of under and over exposing negatives, and divers manipulations of the prints, did not enable me to quite solve the difficulty. The best negative was the one from which the print shown in Fig. 3 was taken.

While from an artistic point of view Fig. 3 is not all that might be desired, it shows markings in some of the grains which are of importance in the present investigation, and which call for careful description. These markings are in the form of concentric lines, the centre being in the situation of the hilum of the grain. These lines are in all cases faint; indeed, to see them at all it is often necessary to reduce the aperture of the diaphragm of the microscope very considerably, or to use oblique light. The illustrations in the various text-books showing concentric lines, as distinct as the outline of the grain, in all the grains are misleading. The lines are apparent chiefly in the larger ellipsoidal grains, but not in all of these, the smaller grains only occasionally showing any trace of such lines. In all cases where these lines are present the latter extend over two-thirds or more of the grain, usually becoming less distinct as they approach the narrow end of the grain; they can only be traced as closed curves in a few cases, in one or two of those nearest the centre. The lines are much more clearly evident in fresh specimens and in those mounted in Canada balsam. When examined in the fresh state, a distinct hilum can be seen in a number of the larger grains. This hilum appears as a black speck or dot near one end, usually the smaller, of the grain: it very

soon becomes invisible in preserved specimens by the penetration into it of the mounting fluid, and is thus not apparent in any of my photographs. In some few cases, however, the hilum becomes opened up and more or less slit-like; and when this occurs it is apparent, as seen in the figures, even in starch preserved in fluid.

In the light of the usual illustrations of potato starch, what I have just said may appear somewhat startling; but as to its correctness there is no doubt, and, unlike many elaborate experiments, it may be verified with very little trouble by anyone with even an elementary knowledge of microscopy. So prone is man to accept without question the statements and illustrations of previous observers that the most misleading descriptions and figures—not of starches alone, but of many other objects—appeared, and still appear, in many of the 'standard' works dealing with the most diverse subjects.

The student is peculiarly unfortunate in this respect. In a great number of cases he is compelled to take the illustrations in his text-books as being accurate, and very often drifts into the custom of holding as correct even those illustrations which he could easily check by examination of the actual specimens, microscopic or macroscopic.*

* An example of this occurred to me two summers ago, when, after dwelling upon some of the points I have just brought out, I was taken to task by several of my students, who, *text-book* in hand, came to me and pointed out that I was wrong as to the concentric lines, as the latter were shown in their books quite as distinctly as the outlines of the grains themselves. So convinced were they that the text book *must* be correct, that it was with difficulty they

8. It only remains, with reference to this starch, to describe its action on polarized light. With the 'ground' dark, the Nicols being crossed, the body of the grain appears quite translucent, but is intersected by two black bands in the form of a cross, the point of intersection being in the situation of the hilum. It is interesting to note that this cross appears on *all* the grains, the very smallest showing it quite distinctly. The cross is never incomplete; the lines always intersect. While in the very small grains the two limbs of the cross are approximately rectilinear, and at right angles to each other, in the larger grains each limb appears as if refracted at the point of intersection. Further, when the analyzer is rotated through an angle of 90° and the 'field' is light, the grains still show this cross, but the body of the grain now appears comparatively dark and the cross light. In comparing potato starch with others, this last point is of some importance.

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were induced to alter their opinion even after I had demonstrated the facts by the aid of a few scrapings from the fresh-cut surface of a raw potato.

CHAPTER V

RYE STARCH

The next starch to which I turned my attention was that of **rye**. From its size it was possible to secure good results with the same magnification as was used in the previous case, and in the absence of any very fine markings in the grain it seemed to me that in this instance dark ground illumination ought to be of special value, and this was subsequently borne out by my results.

1. Rye starch resembles potato starch in being rounded in **outline** and in never showing any sharp angles. It differs from the latter in being of smaller size, in being approximately spheroidal instead of ellipsoidal, in showing no clearly-marked concentric lines in the grain, and in the hilum (when present) being placed in the centre of the grain.

Fig. 4 shows a print from a negative of rye starch, dark ground illumination and the same magnification (116 diameters) as in the case of potato starch having been used. The difference between rye and potato starch is at once apparent from this print; but it is well to admit that, while there is little chance of mistaking one for the other, there are not more than four or five

Fig. 4.—Rye Starch, ×116. (Dark Ground.)

grains in the whole 'field' which are characteristic of rye starch.

2. It will be noticed that the grains are approximately **circular in outline**, and that while the size varies greatly even the largest does not approach that of potato starch in this respect.

3. The characteristic **hilum** is seen in a few of the grains in the form of a cross, which form is due to the hilum being really two fissures in the grain intersecting each other. Occasionally the hilum is composed of three instead of four rays.

In each 'field' there are a number of minute grains, which show the outline as perfectly as any of the larger grains, the rayed or starred hilum, however, being confined to the latter. The grains showing this hilum can be identified at once as rye starch, as they are not present in any of the other commonly occurring starches.

4. Taking seventy of the largest grains in the 'field,' I find that the average **diameter** is nearly $\frac{1}{40}$ mm.

5. Fig. 5 is from another 'field' of rye starch photographed with transmitted light. The only additional fact of any note brought out by this print is that no concentric lines are visible in the rye-starch grain. Very faint concentric lines are, however, observable when the diaphragm is much stopped down or oblique light is used. It may be observed also that in two of the grains there is an indication of a hilum consisting of a **single** fissure. While this might lead to confusion with the leguminous starches, where the hilum is typically slitlike,

the circular outline of the grains in the present instance is sufficient to obviate any such difficulty.

6. Characteristic markings on this grain are in the form of exceedingly faint concentric lines, which by proper modification of the light can sometimes be made out. These lines are closed curves.

7. The action of rye starch on polarized light requires little description. With crossed Nicols each grain is divided by a black cross into approximately equal quadrants, the bands forming the cross being at right angles to each other, and the point of intersection being at the centre of the grain. When the analyzer is rotated through an angle of 90°, so that the field is light, the grains show no special markings, appearing in all respects as when viewed by transmitted light.

It is proper here to observe that when examined in the fresh state the characteristic hilum of this starch is apparent in a larger number of the grains than in preserved specimens, owing to partial or complete obliteration of the hilum in some cases through permeation by the mounting medium.

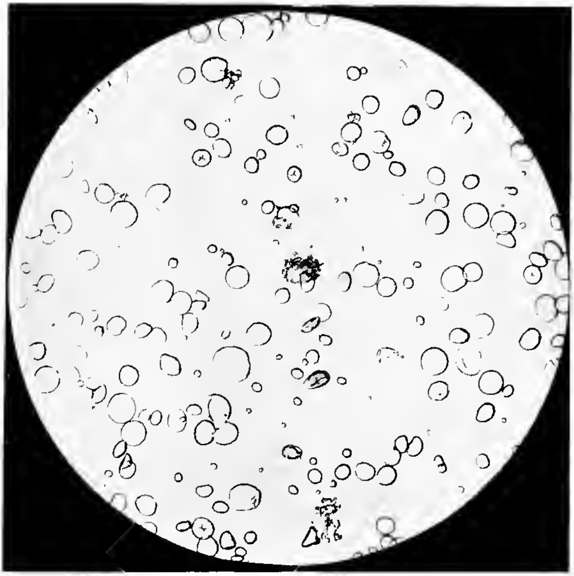

FIG. 5.—RYE STARCH, ×116.

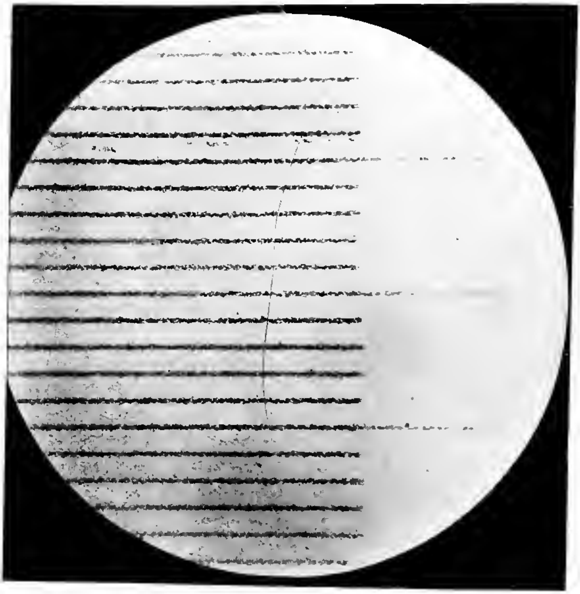

FIG. 6.—MICROMETER SCALE, ×380.

CHAPTER VI

RICE STARCH

On examining rice starch and oat starch under the same conditions as in the case of the two starches already described, it was at once evident that to bring out the contour in a print would require a much higher magnification. I therefore substituted objective No. 7A for No. 3, and took a photograph of the micrometer scale under the new conditions. A print from this negative is shown in Fig. 6, and the magnification was found to be 380 diameters, which seemed to be ample even for the very minute grains of rice and oat starch. It was quite clear to me that, with the small amount of light now available, and which had to be further reduced by stopping down the diaphragm so as to obtain as much contrast as possible, exposure would be very prolonged, and the results possibly more or less disappointing. This I found to be the case, and I may say at once that the most difficult part of the whole of this investigation was to obtain a satisfactory negative of rice starch, the contrast between the grain and the body of the 'field' being almost *nil*, and dark ground illumination being impossible with the objective employed. I took many negatives of rice starch, and a print from the most satisfactory is shown in Fig. 7.

Bearing the magnification in mind, it will be seen how excessively small the grains of rice starch are compared with, say, those of potato starch.

1. The grains of this starch are in the highest degree **translucent**, so much so that if the 'field' is flooded with light it is not uncommon for the student to focus past the grains without observing them.

2. The **shape** of the grain requires careful attention. It belongs to that group of starches which have **angular** and **faceted** grains, differing entirely in this respect from those I have already discussed. It is irregularly polygonal in form, and is usually four or five sided. No typical rice-starch grain shows anything like a rounded outline at any part of the grain. This polygonal shape is apparently brought about by mutual pressure in the cells of the plant, much in the same way as gall-stones often become polygonal and faceted by mutual pressure in the gall-bladder.

It will be noticed, too, that in some parts of the 'field' several grains cohere, fitting into one another by their faceted sides; but where this compound grain (if it may be so termed) exists, it may be noted that **the outline of the whole is frequently more or less angular.** The importance of this last point will be observed when we come to deal with oat starch.

3. The **size** of the grain is somewhat difficult to determine, as even the hundredth part of a millimetre is scarcely fine enough for its measurement. The average diameter, however, is about $\frac{1}{250}$ mm.; and the variation in size, as will be

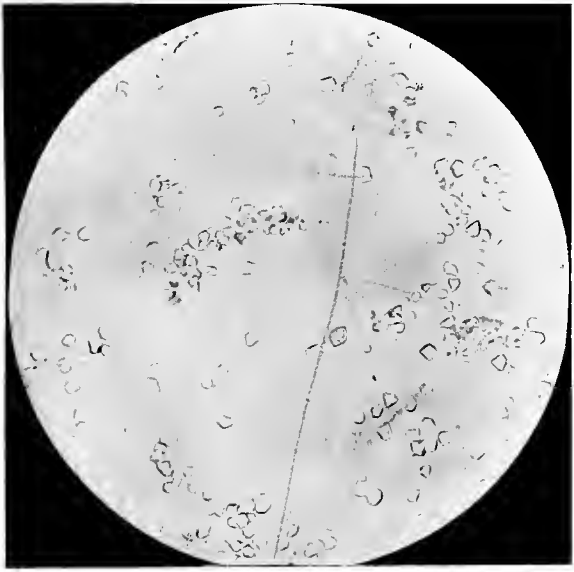

FIG. 7.—RICE STARCH, $\times 380$.

seen from the print, is decidedly less than in the case of those starches previously considered.

4. The **surface** of the grain is practically flat. In a few grains careful focussing gives an indication of a shallow depression in the centre, like that in the red blood corpuscle of the Mammalia, but this quality is not sufficiently constant to serve as a characteristic of this grain.

5. The **hilum** is absent in rice starch; nor is there any indication of the concentric rings noticed in potato starch.

6. There are no **markings** of any kind in the individual grains of this starch.

7. Rice starch has no action on polarized light.

CHAPTER VII

OAT STARCH

OAT starch has many points of resemblance to rice starch. Thus, the grains are small, angular, faceted, and show no hilum or concentric rings. On the other hand, there are a few important differences now to be noted.

Fig. 8 shows a print from a negative of oat starch taken with transmitted light and with the magnification (380 diameters) previously employed for rice starch.

It will be noticed that while most of the grains are small, and resemble superficially those of rice, there are a number of comparatively large **compound** grains, or glomeruli, evidently consisting of a number of the smaller grains in a composite form. Still more important is it to note that these compound grains **have a uniformly rounded outline**, and are again roughly ellipsoidal in form. It is this rounded outline in these compound grains which, in addition to the larger size in this case, distinguishes oat starch from that of rice; in the latter, as already noted, any aggregation of grains usually shows a more or less irregular and angular outline. In the figure it will be noted that in the compound grains particularly the angular and faceted

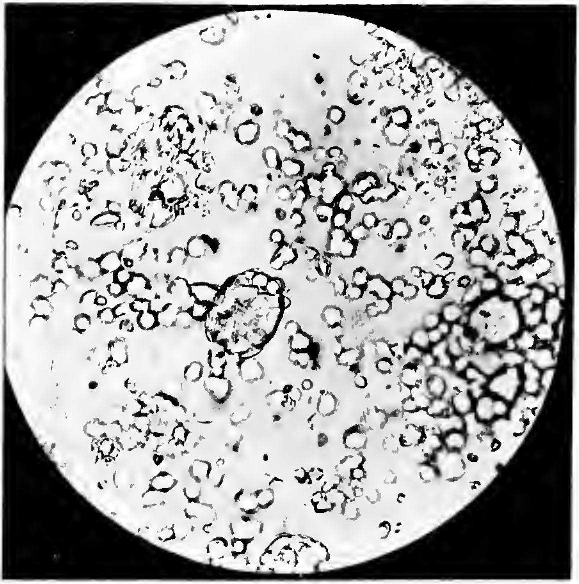

FIG. 8.—OAT STARCH, × 380.

nature of the individual grains is well marked; this does not show well in the discrete grains.

Under this power it was quite impossible to get the single and composite grains into focus at the same time, and the latter are shown at the expense of the former. In the print there are three of these compound grains, but the one nearest the centre was focussed specially, and to it I shall more particularly refer.

1. This compound grain distinctly shows the **rounded outline** already mentioned. While the individual grains near the periphery of the compound grain are distinctly outlined, it will be noticed that the outlines of the others become less and less distinct as the centre is approached, and this is due to the convexity of the surface of the compound grain, the surface at the centre being within the focus of the objective. The long diameter of this grain is about $\frac{1}{30}$ mm., and the short about $\frac{7}{250}$ mm.

2. The detached grains which are in focus show that they resemble the grains of rice starch with regard to their **angularity, facetedness, polygonal shape,** and **absence of hilum and concentric rings,** but their average **diameter** is nearly $\frac{3}{500}$ mm., or about one and a half times the diameter of the grain of rice starch.

Fig. 9 is from a print intended to show the discrete grains more distinctly than is possible when the compound grains are in focus. It presents otherwise no additional features of interest.

3. From the manner in which the grains occur in the glomeruli, it is evident that the **surface** of the individual grains is often slightly convex on one side, and flat or slightly concave

on the other. In the field there are a few rounded grains, a comparatively rare occurrence in oat starch, and one practically never seen in that of rice. It is necessary to note that the proportion of compound grains present varies considerably in different samples of starch. This may be due, partly at least, to purely mechanical causes.

4. As in the case of rice, oat starch shows no markings in the individual grains, although, of course, the compound grains show markings due to the outlines of the component single grains.

5. Oat starch has no distinctive action on polarized light. With crossed Nicols the compound grains are visible, as if viewed by dark ground illumination, but there are no constant or characteristic markings.

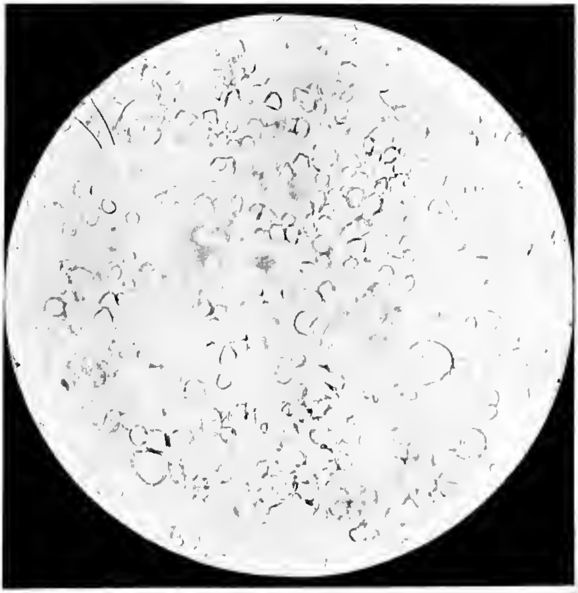

FIG. 9.—OAT STARCH, ×380.

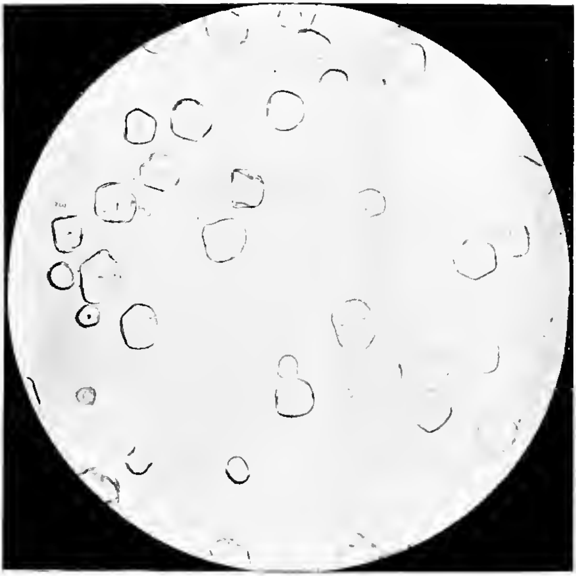

Fig. 10.—Maize Starch, × 380.

CHAPTER VIII

MAIZE STARCH

MAIZE starch forms a stepping-stone, with regard to size, between the very small grains just considered and the larger grains of potato and rye. On exposing a plate and taking a print, I found that a magnification of 116 diameters was quite insufficient to give anything like detail in the outline; and, as I wished to avoid varying magnifications as much as possible, I fell back on that (380 diameters) used for rice and oat starch, although this was, if anything, too great. Fig. 10 was taken with transmitted light in the usual way.

1. It will be seen that this starch, like that of rice and oats, belongs to the group having **faceted grains.**

2. In **outline** it is **polygonal**, but rounded grains are bere comparatively frequent, although a grain with a regular curve is rare.

3. The **size** of the grains is fairly uniform. The average diameter of those shown in the prints is about $\frac{1}{70}$ mm., the smallest being $\frac{1}{120}$ mm., and the largest $\frac{1}{50}$ mm.

4. The **surface** of the grain of maize starch is rarely flat; it almost always shows a slight thinning towards the centre, and it is often **very uneven.**

5. There is not the slightest indication of **concentric rings** in any of the grains shown. Concentric rings are only found in starch grains with rounded outline.

6. The **hilum in fresh specimens** is almost always very strongly marked, and is situated at the centre of the grain. In the fresh state it appears, under moderately high powers, as a comparatively large, black, stellate body, the 'rays' of which, however, never approach near to the free border of the grain. In preserved specimens, as will be seen from the prints, the hilum shows only a faint indication of this stellate appearance, and is reduced to a mere dot in the centre of the grain or disappears altogether. In one grain in the print this stellate arrangement of the hilum remains perfectly distinct.

Fig. 11 is from a print obtained from a negative taken with an 8 mm. semi-apochromatic objective. It was taken after I had concluded the investigation, and is the only one of the kind which appears in the series. The magnification is 185 diameters. It does not call for any special description.

7. With polarized light maize presents appearances similar to those given by rye, showing the black cross when the 'field' is dark.

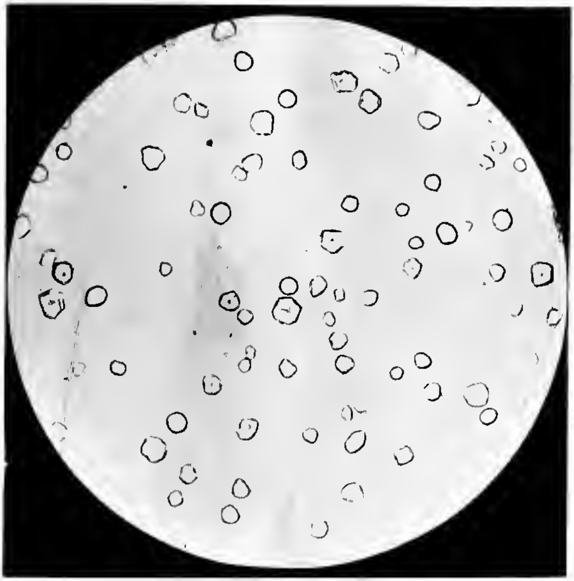

Fig. 11.—Maize Starch, ×185.

CHAPTER IX

PEA STARCH

Pea starch has special features which are more or less typical of the starch grains of the Leguminosæ in general, but I selected pea starch for examination as the commonest and most important of the group. With this starch I was able to revert to the magnification employed for potato and rye starch, the higher magnifications revealing no additional details.

Fig. 12 is from a negative obtained in the usual way. Fig. 13 is from another 'field' taken with dark ground illumination; both are magnified 116 diameters. It will be at once apparent that the grains of pea starch are totally unlike the three last considered, and present well-marked differences from those of potato and rye.

1. The grains of pea starch are highly **translucent** and refract light strongly, as the deep and bold outline of the grain shows.

2. They belong to that group of starches whose grains are **rounded in outline** like potato starch; the grains of pea starch never show, under natural conditions, the faintest trace of angularity in outline.

3. The **shape** differs materially from that of any starch yet described. The **characteristic** grain

of pea starch (in common with the other leguminous starches) is irregularly **reniform** in shape, and in both 'fields' shown in the figures quite a number of the grains are of this shape. From this reniform shape, however, we find deviations, many of the grains lacking the characteristic concavity, and being thus more or less elliptical. Other grains show a slight concavity on **both** sides of their long axis, while a very few are somewhat irregular in outline.

Practically all the grains **have a short and a long diameter**, whether the reniform outline is distinct or not, this feature being much more constant than even in the case of potato starch; it is very rare indeed to find a grain of pea starch which has an approximately circular outline.

In practically all cases both ends of the grain are alike, as shown in both figures; there is no narrowing at one end, as in the case of many of the grains of potato starch. This is a point of some considerable importance, as in nearly all the other starches with elongated grains and rounded outlines the ends of the grain are not similar.

4. The **size** of the grains of pea starch is subject to surprisingly little variation, compared with many of the other starches. Very minute grains are uncommon, while a large number (and these the largest) are of practically the same size. These latter average about $\frac{1}{28}$ mm. in the long diameter, and $\frac{1}{40}$ mm. in the short, the latter dimension being more constant than the former. The smallest grain in Figs. 12 and 13 measures $\frac{1}{50}$ mm. in the long diameter, and $\frac{1}{56}$ mm. in the short.

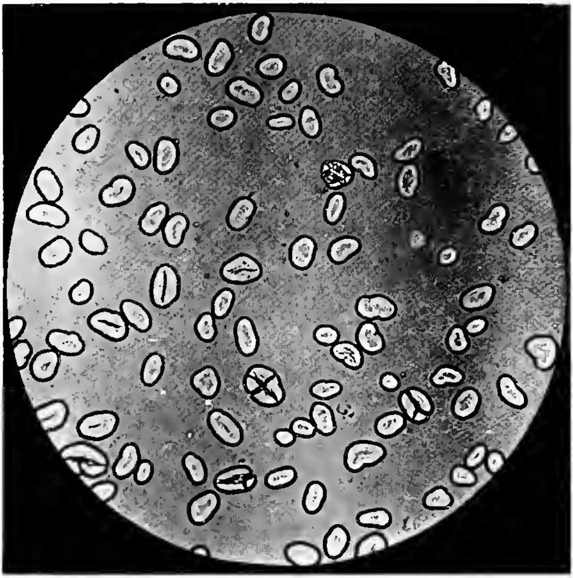

FIG. 12.—PEA STARCH, ×116.

5. While the **surface** of the grain is convex at the sides, it becomes slightly concave towards the centre, where a shallow depression can sometimes be made out by careful focussing. This depression could only be distinctly brought out by over-exposure of the print.

6. The **hilum** of this grain (see Fig. 12) is also unlike that of any starch yet discussed. Where it is seen (and this is not in all cases) it is in the form of a slitlike dark line in the situation of the depression previously mentioned; it runs in the direction of the long axis of the grain, but not extending to either end. This line or slit is always perfectly simple **in the unbroken grain**, never assuming the stellate form seen in the case of rye. A few of the grains shown in the figures are fractured, and while the original longitudinal hilum is quite evident even in these cases, the line of fracture often runs at right angles to this line. These accidental fissures can be distinguished from the original hilum by their reaching the surface of the grain at one or both of their ends, and by showing a notch or cleft on the free border of the grain. One of the grains in Fig. 12 shows a rupture extending almost from end to end of the grain, and following the course of the hilum. Many of the grains, however, show no distinct hilum, but simply a depression in the long axis of the grain.

7. With regard to any finer **markings** in the interior of the grain, Fig. 12 alone gives much information. From this it will be seen that there is a distinct appearance of the grain being built up, as it were, of concentric layers round

the hilum. The appearance here is like that given by a section of a urinary calculus, or the *corpora amylacea* found in the prostate gland. These lines or layers form closed curves.

8. The effect of this starch on polarized light is similar to that of potato starch (*q.v.*). With crossed Nicols one peculiarity is worth noticing, and that is that instead of the usual black cross there is in many instances a double V-shaped band at each end of the grain, the apex of each V being at the end of the hilum.

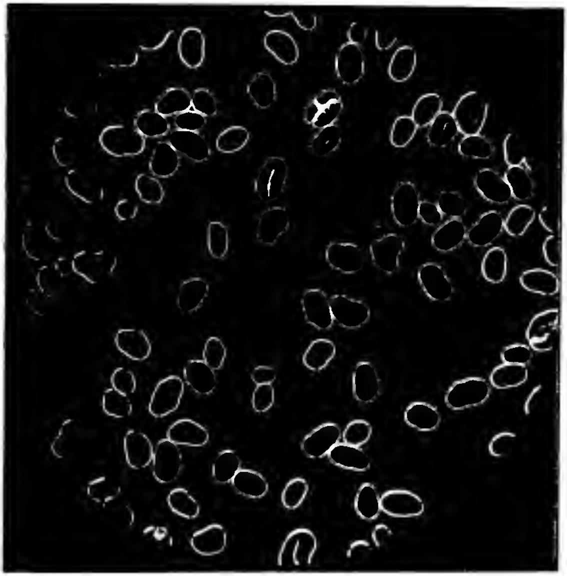

FIG. 13.—PEA STARCH, ×116. (DARK GROUND.)

CHAPTER X

SAGO STARCH

SAGO starch resembles pea starch in the size of the grains, but the grains of sago starch have well-marked features which distinguish them from those of any starch yet described.

Fig. 14 shows a print from a negative of sago starch taken at the magnification of 116 diameters, and it will be at once noticed that many of the grains are of rather an unusual shape.

1. The grains of this starch are less **translucent** than those of any of the starches yet considered, but the difference is not sufficiently striking to be of much service in description.

2. The **outline** requires careful notice. In a general way it may be said that the grains are again rounded in outline; but while this term might be applied without qualification to a considerable proportion of the grains, it is evident from the print that in quite a number of cases in the 'field' shown the continuity of this outline is broken abruptly at one end, as if the grain had been broken across at this point. The latter may thus be said to be irregular in outline, and they are perhaps more characteristic of sago starch than the uniformly rounded grains.

3. In **shape** the uniformly rounded grains are similar to those of potato starch, but without

the flattened surface of the latter. They are ellipsoidal, usually larger at one end than the other, and in most cases show the hilum near the narrow end. The appearance of the irregular grains always suggests to me the 'tears' of gum mastic, and with the latter I always compare them with regard to shape. These grains give at first the impression of their being parts of larger grains forcibly broken off; but if this were the case, one would expect to find broken-off parts in each 'field,' and these showing no hilum, whereas such parts are not found in practice. This is the first example in this book of a combination of curves and angles in the same starch grain. It is also remarkable that for some distance from the line of apparent fracture the sides of the grain are approximately parallel. All the grains have a short and a long axis; but while in the case of the grains with uniformly rounded outlines these axes may be represented by straight lines, in the irregular grains the long axis is frequently bent slightly to one side, especially at the rounded end.

4. There is considerable variation in the **size** of the grains, not only in the 'field' shown, but also in others. The average greatest short diameter of six of the largest irregularly-shaped grains in Fig. 14 is $\frac{3}{100}$ mm., the long diameter of the same grains being $\frac{9}{200}$ mm.; taking the whole 'field,' the average long diameter is about $\frac{7}{200}$ mm., and the short $\frac{9}{400}$ mm. Very small or very large grains are rare.

5. The **surface** is more convex than that of any starch yet described. The resemblance to the 'tears' of gum mastic holds in this respect

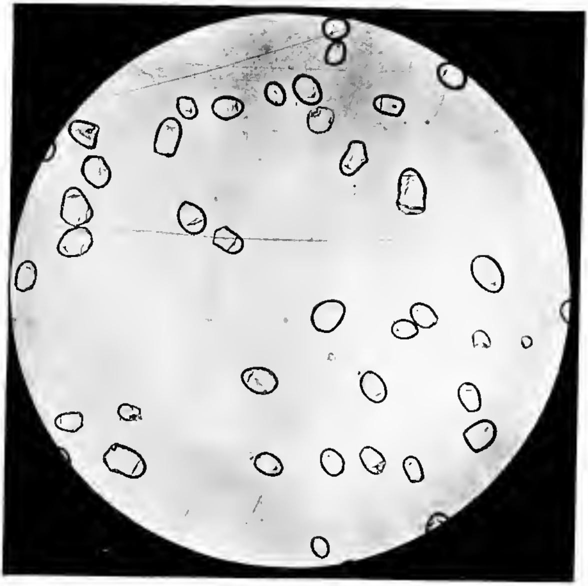

FIG. 14.—SAGO STARCH, ×116.

also. A section across the long axis of one of the irregularly-shaped grains would give an approximately disc-shaped surface; thus, they are not flattened like the grains of potato starch. The uniformly rounded grains, however, are usually very slightly flattened.

6. The **hilum** of the sago-starch grain is situated, in practically every instance, near the narrow end of the grain; in the case of the irregularly-shaped grains it is invariably near the rounded end. It appears in the form of a line or slit running parallel to the short axis of the grain. It occasionally shows a slight tendency to fissure. It often shows irregular branching in the direction of the long axis of the grain. In the very small grains no hilum is observed.

7. The **markings** on the grain of sago starch, other than those already described, are in the form of a few faint, usually incomplete concentric lines in some of the grains.

8. With polarized light sago starch acts similarly to potato starch.

CHAPTER XI

TAPIOCA STARCH

Tapioca starch is often described as being like sago starch in miniature, but this can only be held to be a very rough description. The grains are undoubtedly very small and rounded, and many of them appear as if one end were cut off; but here the resemblance may be said to cease as far as their microscopic appearance is concerned.

Fig. 15 shows a print from a negative taken at a magnification of 116 diameters, and the small size of the grains, as compared with those of sago, is at once apparent. Even this print shows, however, that a large number of the grains are practically circular in outline, and that the hilum is in the form of a dot or line about the centre of the grain.

1. The grains of tapioca starch are rather more **translucent** than those of sago, but this is chiefly if not entirely from their smaller size.

2. The **outline** is frequently almost circular; but a number of the grains show some resemblance in outline to the grains of sago starch, having one end rounded and the other appearing as if cut short transversely.

3. The **shape**, taking the grains as a whole, may be said to be that of an ellipse, but with

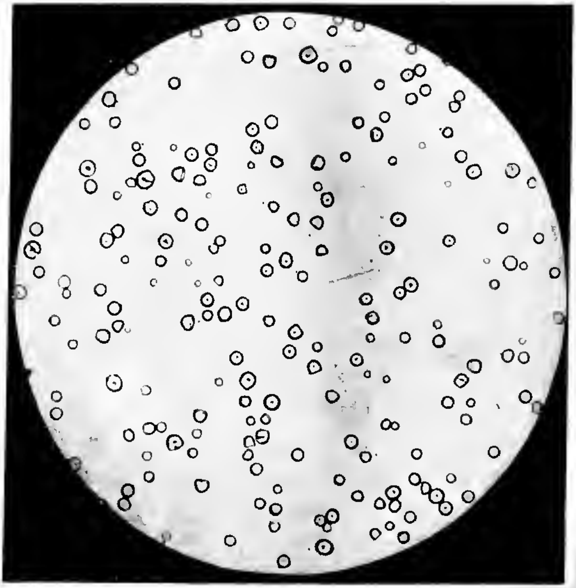

Fig. 15.—Tapioca Starch, ×116.

the long and short axes differing but slightly. The curve is interrupted, in a number of cases, by flattening of one end of the grain, this flattening rarely showing the jagged, fractured appearance found in sago starch. The parallelism of the sides noted in the case of those irregularly-shaped grains of sago starch near the place of apparent fracture is not seen here. Some of the grains are practically spherical.

4. The **size**, again, varies considerably, but the general average diameter may be put down as about $\frac{3}{200}$ mm.

5. The **surface** is uniformly convex, resembling sago starch in this respect.

6. The **hilum** is at the centre of the grain, and is usually in the form of a rather indefinite slit extending about half-way across the grain. In some cases the hilum is star-shaped, like that of maize, but the two grains are, of course, otherwise easily distinguished.

7. With low powers no additional **markings** can be discerned in the grains of this starch, and even the higher powers only reveal in some cases minute fissures radiating from the hilum. There is no definite appearance of concentric rings or layers in the great majority of the grains. Taken as a whole, tapioca starch has few characteristic features.

8. Its action on polarized light is similar to that of rye, the black cross appearing only when the 'field' is dark.

CHAPTER XII

WHEAT STARCH

From economic considerations wheat starch is perhaps the most important of all. Adulteration of wheat flour with other starches has been largely practised in the past, and the best safeguard for the future is an accurate knowledge of the morphology of pure wheat starch.

Fig. 16 is from a negative of a 'field' of pure wheat starch, taken with transmitted light and at the magnification of 116 diameters. My experience of microphotographic technique was by this time sufficient to enable me to obtain a print with a fair proportion of the sharpness and definition of an engraving combined with that fidelity to detail which photography alone can give.

1. The **translucency** of these grains is very marked, and they refract light strongly. I have frequently found students who were looking at this starch under the microscope describe it as oil globules or milk, and this description is not by any means so absurd as might at first sight appear.

2. The **outline** of the grain of wheat starch is always uniformly rounded; but while in many cases it is approximately circular, this occurs much less often than in rye starch. In the

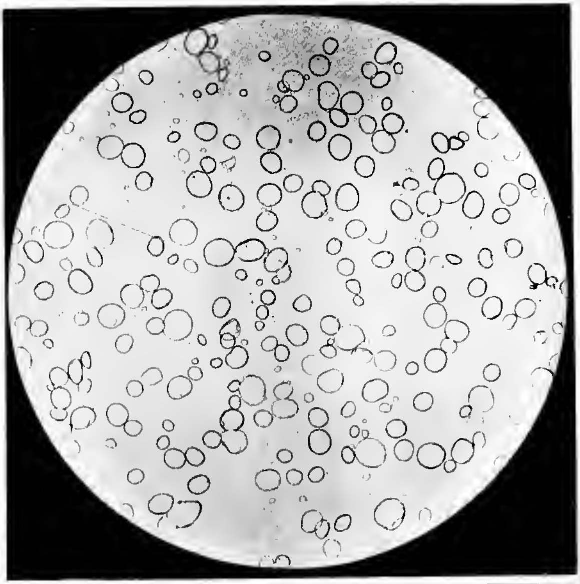

FIG. 16.—WHEAT STARCH, ×116.

majority of cases the outline resembles the result of a good attempt at drawing a circle by hand, the continuity of the curve in the case of the grains, however, being unbroken.

3. The **shape** I describe as **lenticular.** In the text-books the grains are usually described as disc-shaped; but the inaccuracy of this description may easily be proved by careful focussing, or by examining a fresh specimen with the microscope inclined from the perpendicular, when it will be observed that the outline of any grain as it traverses the 'field,' rotating on an axis as it does so, does not show flat surfaces. It may be that flat grains have been found by others; but if so, such an appearance is not typical of this starch, and is certainly unusual.

There is comparatively little variety in the shape of the grains of wheat starch, all from the largest to the smallest exhibiting practically the same shape, any variation being usually simply slight elongation of the grain. Grains, usually small, of irregular shape are sometimes found.

4. It is usually stated that, with regard to the **size** of the grains of wheat starch, while there are large and small grains there are very few of intermediate size. To the latter part of this I cannot subscribe. I admit that there is a large proportion of the larger grains nearly uniform in size, and that there is also a considerable proportion of very small grains; but from an examination of many 'fields' I am unable to substantiate the statement that inter-

mediate-sized grains are comparatively rare, nor, indeed, would it be easy to account for this, supposing it to be true. In the 'field' shown in the prints it is obvious that there is no lack of grains of medium size, although the proportion of these is not so great as one might *a priori* expect.

The average diameter of twelve of the largest grains in Fig. 16 is a little over $\frac{3}{100}$ mm. Taking the whole 'field,' however, but excluding the very minute grains, the average diameter is nearly $\frac{2}{100}$ mm.

5. From what I have already said as to shape, it is evident that the **surface** of this grain is almost uniformly convex from periphery to centre, and is perfectly smooth.

6. The **hilum** of the grain of wheat starch is observed only in a small proportion of cases, and practically never in the very small or even the medium-sized grains. When present it appears as a dark spot; this spot is rarely in the centre of the grain, being almost invariably slightly eccentric. It does not show any tendency to fissuring or stellation.

7. The grains of wheat starch only occasionally show a few exceedingly faint **concentric rings**, although in certain well-known text-books concentric rings are described and figured as clearly evident. It is always difficult, and often impossible, to see these rings at all.

8. With polarized light wheat starch shows appearances similar to those given by rye (*q.v.*).

Fig. 17 gives no additional information, but it is instructive to compare this print with a

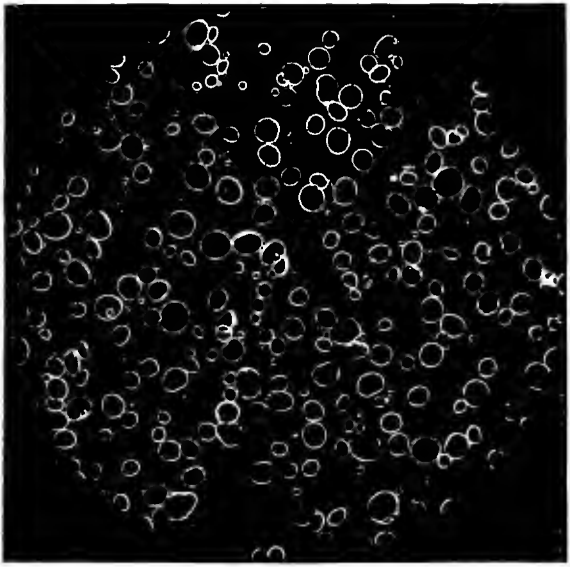

FIG. 17.—WHEAT STARCH, ×116. (DARK GROUND.)

similar one of rye starch (Fig. 4); the 'thinness' of the outline of wheat starch compared with that of rye is remarkable.

It may be mentioned that the higher magnifications did not reveal any additional details, and I have not thought it advisable to show any results obtained from such magnifications.

CHAPTER XIII

BARLEY STARCH

The starch grains of barley present considerable similarity to those of wheat, and this is peculiarly unfortunate when it is remembered that perhaps the commonest adulteration of wheat flour is with barley flour. It is the more important, therefore, to closely study the morphology of this grain.

Fig. 18 shows a 'field' of barley starch from a negative taken with transmitted light, the magnification being again 116 diameters. On comparing the figure with those of wheat starch, the most obvious difference is the smaller size of the grain of barley starch; but, while this is no doubt a very important point, it is not nearly so conclusive as it might seem. While the constancy of the average size of the grains of any one starch is remarkable, there is no doubt that different samples of the same starch may show 'fields' with the average size of the grains slightly above or below that found in the present investigation.

1. Very little need be said regarding the **translucency** of the grain of barley starch. It is scarcely so translucent as wheat, but nevertheless offers no definite obstruction to the passage of light through it at all parts.

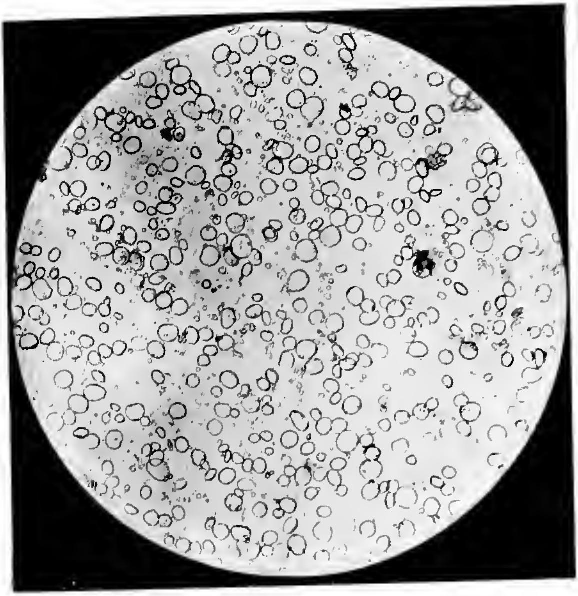

FIG. 18.—BARLEY STARCH, × 116.

2. In a general way the **outline** of this grain may be said to resemble that of wheat starch. The grains are uniformly rounded in outline, and many of them approach the circular form as in wheat; but it will be noticed that in barley starch a much larger proportion of the grains are elongated. Some of the grains come almost to a point at each end, and show a **lenticular** outline.

3. In **shape** the grains of this starch are, like those of wheat starch, approximately lenticular in those cases where the outline is nearly circular. All the grains are smoothly rounded; here also flat grains are practically unknown. Very infrequently a grain may be found somewhat sausage-shaped, and very rarely one may find an irregularly-shaped (but never angular) grain.

4. The **size** of the grain of barley starch is of the utmost importance as a means of differentiation from others, *e.g.*, rye and wheat, having a more or less similar form. The average diameter of the grains in Fig. 18 is a little over $\frac{3}{200}$ mm.; the largest grain does not exceed $\frac{1}{40}$ mm. in diameter, and only a very few at all approach this size. It is often stated that intermediate-sized grains of this starch are rare. I have already emphasized the erroneousness of this description generally applied to the grains of wheat starch; and in the case of barley starch the error is still more pronounced, as will be seen from a glance at Fig. 18, such grains being present in what might be termed a normal proportion. In barley starch there are, however, a large number of very minute grains, so small that measurement is out of the question; wheat

starch contains only a very small proportion of such grains.

5. From what has been said regarding the shape of the grain of this starch, it will be evident that the **surface** is convex and smooth.

6. The **hilum** of this grain is apparent in even fewer cases than in wheat starch. When it is evident, it appears again in the form of a dark dot, more or less eccentric in position, and showing no tendency to subdivision or extension.

7. There are no characteristic **markings** on the surface of the grain of barley starch. Concentric lines in the grain can only very rarely be made out, although the darkening as the periphery is approached often gives an appearance as if the grain were built up of concentric layers.

8. On polarized light the grains act similarly to those of rye (*q.v.*), but it is to be noticed that here the black cross is always very indistinct.

From the print it will be observed that in barley starch there is a tendency for small areas of amorphous débris to appear in the 'field'; this is so constant as to be of some value in identifying the starch.

Barley and Rye.

Fig. 19 is from a negative taken by dark ground illumination, and exposed twice, first to a 'field' of barley starch and afterwards to one of rye starch. Several very interesting facts are revealed by this print. It will be observed that the definition of the barley starch is not at all

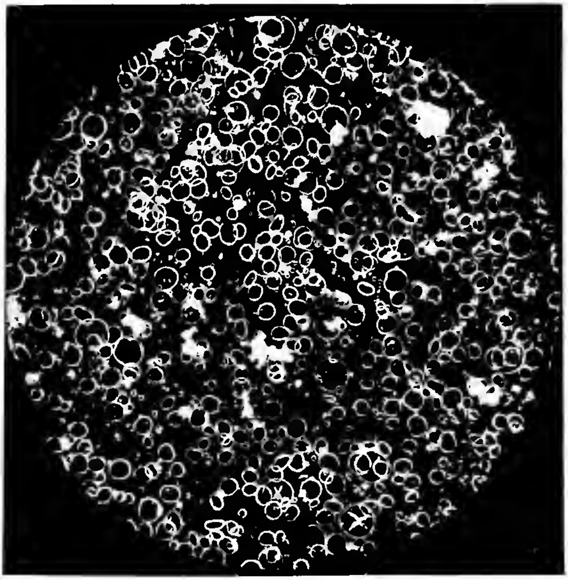

Fig. 19.—Barley and Rye Starches, ×116.
(Dark Ground.)

impaired by the second exposure, and the characters of both grains come out quite clearly, as even where the grains are superposed in the print the translucency of all the grains allows both outline and hilum to appear wherever present. There are several characteristic grains of rye starch (recognised by the rayed hilum) present, while the general appearance of the 'field' is indubitably that of barley starch. The large circular grains without hilum or markings cannot be identified; they might be either wheat or rye starch.

CHAPTER XIV

ARROWROOT STARCHES

The arrowroot starches form a group by themselves, in which the characters vary within certain limits, rendering it impossible to give one description which will be applicable to all in every detail. For the purpose of this investigation I have selected two: one, Bermuda arrowroot, representing the commoner forms; the other that of tous-les-mois, being interesting as having much the largest grains of any of the more commonly occurring starches.

Bermuda Arrowroot Starch.

Bermuda arrowroot starch is very important from a dietetic point of view, as it is largely prescribed for invalids. It appears to be more easily digested than some of the other starches which, masquerading under various euphemistic names, and being usually composed chiefly if not entirely of maize starch, are often substituted without a due appreciation of the dietetic advantages inherent in pure arrowroot starch.

Fig. 20 shows a 'field' of Bermuda arrowroot starch, taken from a negative obtained by transmitted light. The magnification is again

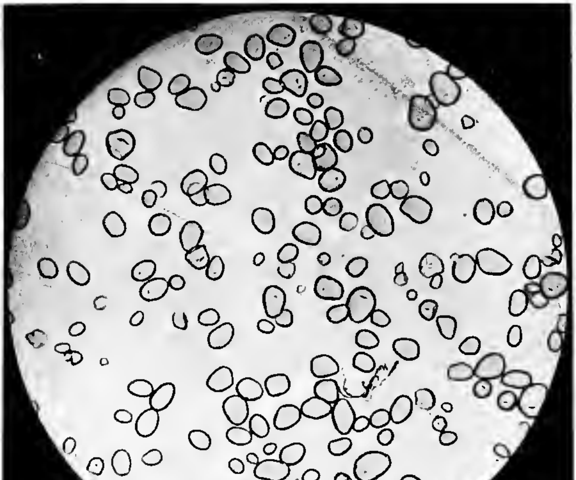

FIG. 20.—BERMUDA ARROWROOT STARCH, ×116.

116 diameters. The higher magnifications gave in a few cases slight additional details; but this, in my opinion, was not sufficient to render it desirable to show figures at a higher magnification, more especially as it was difficult, owing to the comparatively large size of the grains, to get a negative giving clear outlines at a magnification much higher than that shown.

1. The grains of this starch are highly **translucent**, the interior of the grains sometimes appearing even clearer than the remaining parts of the 'field.'

2. The **outline** is not so distinctive as in some of the starches already considered, there being more irregularity in the case of this starch. While it may be said that the grains as a whole are uniformly **rounded** in outline, there are a few in nearly every field which show an abruptly cut-off end, giving an appearance suggestive of a truncated grain of sago starch. All the larger grains and many of the smaller ones have one end more rounded than the other, a fair proportion indeed having an almost perfectly egg-shaped outline. This difference is more marked here than in potato starch.

3. In **shape** the grains are lenticular and flattened, so that a transverse section would show an appearance like a section of a biconvex lens. Some of the grains are less flattened than others, those abruptly cut off at one end resembling sago starch in form as well as in outline. A very few of the grains are quite irregular both in outline and shape.

4. This grain closely approaches that of pea starch in **size**; but, as will be seen from what

has been previously said, the short diameter of the grain of Bermuda arrowroot varies at different levels, while that of pea starch is almost uniform. The variation in size is not very great. There are a number of comparatively small grains (none of these, however, being nearly so minute as the smallest grains of barley starch), but those of characteristic form vary very slightly in their diameters. The average long diameter of the grains of egg-shaped outline in Fig. 20 is nearly $\frac{1}{28}$ mm., the greatest short diameter being about $\frac{1}{45}$ mm. Taking all the grains in the 'field' into account, the average diameter would be less; but measurement of the smaller grains would be of doubtful utility.

5. The **surface** in practically all cases is uniformly, though slightly, convex; this, of course, follows from what has been already said regarding the shape of the grain.

6. The **hilum** demands particular attention. It will be seen from Fig. 20 that a fair proportion of the grains show a hilum, and in practically all cases it is situated near the **broad** end of the grain, though nearer the centre than in the case of potato starch.

Unfortunately, in preserved specimens of this starch, the hilum in many cases loses much of its characteristic appearance. In the figures it appears as a black dot, or in some grains as a transverse line or slit, in the situation already mentioned. Even where it appears as a slit this never extends more than a very short distance on each side of the line of the longitudinal axis, nor does it ever show any tendency to fissuring or branching.

In the fresh specimen, however, the hilum frequently shows a very characteristic appearance, being composed of a cross formed by two slightly curved lines intersecting at an acute angle, with the concavities looking towards the pointed end of the grain; and from their position, form, and fineness giving an appearance which cannot be confounded with, for example, that of the hilum of rye starch.

7. With regard to **markings**, many of the grains show exceedingly faint rings concentric with the hilum, as in potato starch, but they are even less easily seen than in the case of the latter. To see these lines, the light has to be cut off to such an extent that I found it impossible to get a negative to show them at all. The majority of the rings are closed curves. There are no other markings on the grain.

8. The grains of this starch act on polarized light in a similar manner to those of potato starch (*q.v.*).

Tous-les-Mois Starch.

The grains of this starch are remarkable for their large size; they are by far the largest found in any of the well-known starches. While they present some features similar to the arrowroot starches as a class, they show also some analogies to a few of the other starches, and for this reason merit a special description.

Fig. 21 shows a 'field' of tous-les-mois starch, taken at a magnification of 116 diameters with transmitted light. A much lower magnification would have been quite sufficient in this case, but

for purposes of comparison I thought it best to adhere to the magnification adopted for all the starches except those having very minute grains, especially as on account of the flatness of the grains no loss of definition was experienced at this magnification. The higher magnifications not only gave no additional information, but seemed even to obscure some of the details brought out by the comparatively small magnification of 116 diameters.

1. In **translucency** this grain closely simulates that of Bermuda arrowroot starch, in spite of the fact that the former is considerably thicker than the latter.

2. The **outline** is more irregular than in the case of Bermuda arrowroot starch, although one or two grains almost perfectly oval in outline may be seen in the field. It is well to remember also that the 'field' shown contains a small number of the grains compared with that of Bermuda arrowroot at a similar magnification; thus deductions drawn from Fig. 21 are liable more or less to the 'error from paucity of data' (an error which every teacher of public health knows is sometimes a most serious one when dealing with vital statistics). In practically every case the grains are again uniformly rounded in outline, any grain not fulfilling this condition being most probably aberrant. The outline of a number of the grains is approximately elliptical, deviation from this being chiefly in the direction of slight broadening of one end and narrowing of the other, the grains resembling in this respect those of potato starch. A few of the grains show a tendency, never strongly

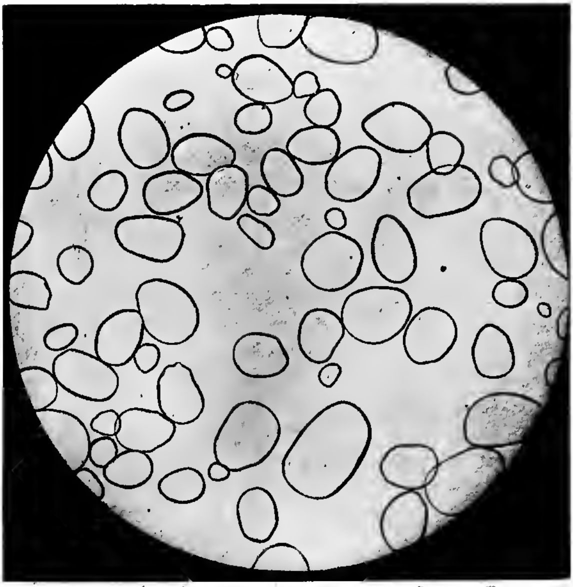

Fig. 21.—Tous-les-Mois Starch, × 110.

marked, to circularity in outline; in such cases the uniformity of the curve is broken at several points. On the whole the outline resembles that of the potato-starch grain more than that of the grain of Bermuda arrowroot starch.

3. In **shape** the grains are much flattened, relatively more so than those of potato or Bermuda arrowroot starch; but like both the latter the grains are uniformly convex on both sides. A transverse section would thus show an appearance similar to that obtained by a cross-section of a biconvex lens of small curvature. The grains, from their shape, have a short and long diameter, and these may be represented by straight lines at right angles to each other. In other words, the grains are not bent to one side or other as was found to be the case in the grains of sago starch.

4. While they vary within fairly wide limits as to **size**, the grains are much larger than those of any other starch occurring in ordinary food-stuffs. In the field shown the largest grain measures no less than $\frac{1}{8}$ mm. in the long diameter, and nearly $\frac{1}{13}$ mm. in the greatest transverse diameter. Of course, the average size of the grains is much less than this, and is probably about $\frac{7}{100}$ mm. and $\frac{5}{100}$ mm. respectively, but is certainly much greater than that of the average potato-starch grain, which latter comes next to it in point of size among the starches described in this book. Small grains are not uncommon, but the very smallest is rarely less than $\frac{3}{200}$ mm. in diameter, there being no appreciable difference of diameters in the smallest grains.

5. The **surface** is smooth, and is only very slightly and uniformly convex.

6. The **hilum** is not very apparent in the majority of the grains. When it is observed it appears as a dark spot near the small end of the grain, in the same position in fact as the hilum of the potato-starch grain. Like that of the latter, too, it shows no tendency to polymorphism; one never finds it appearing as a line or slit, or having a stellate or rayed form. It is rare to find a well-marked hilum in any but the larger grains.

7. The **markings** on this grain are (apart from the hilum) in the form of concentric rings of large radius, particularly well marked in the larger grains, and at the end furthest from the hilum. Of all the commonly occurring starches, this one shows these concentric rings most clearly; but I must emphasize the fact that even here they are really faint, while *comparatively* well defined. They average from twenty to forty or over in number in the larger grains. These rings were clearly shown in the photograph from which Fig. 21 is taken, and are even more distinct on a lantern slide which I took from the same negative. It is rare to find the curve a closed one; in most cases it gradually becomes less and less distinct, and is finally lost before it reaches the level of the hilum.

8. The appearances presented by this starch when examined by polarized light are exactly similar to those given by potato starch (*q.v.*).

CHAPTER XV

HARICOT BEAN STARCH

THE starches of those members of the Leguminosæ used for human food possess characters similar in the main to those of pea starch, already described. It appeared to me, however, that the starch of haricot bean showed some modifications which warranted a special description, having regard to its extensive use as an article of food.

Fig. 22 is from a print taken from a negative of haricot bean starch, at a magnification of 116 diameters, and photographed by transmitted light. The general resemblance of the grains to those of pea starch will be obvious on comparing the two, and the differences in detail are brought out in the following paragraphs.

1. This starch is distinctly less **translucent** than any of those previously described, and the difference in this respect from pea starch, a member of the same group, is quite noticeable. This fact allowed of a comparatively considerable contrast being obtained, the result being that the grains are not only of well-defined outline in the print, but the shading due to the shape of the grains was also well shown in the photograph.

2. The **outline** of the grains resembles roughly

that of pea starch, but is not nearly so uniform over a number of grains as in the latter case. In the 'field' shown it is easy to pick out quite a number of the grains which have the reniform outline highly characteristic of most of the common leguminous starches, but the majority of the grains do not conform to this description. At the same time, all the entire grains show a uniformly rounded outline, as in the case of potato, rye, pea, wheat, barley, and arrowroot starches. In a number of cases the grains have an approximately elliptical outline. Others, again (and these the smaller grains) show an outline which is almost circular. The latter are present in considerable proportion in every 'field,' haricot bean starch differing markedly from pea starch in this respect, grains of circular outline in the latter case being comparatively rare. In all cases where the grains are not circular, there is no narrowing at one end of the grain and broadening at the other, haricot bean starch being similar to pea starch in this particular, and differing from potato and arrowroot starches.

3. In **shape** the grains are, where the outline is similar, like those of pea starch. The grains of circular outline are flattened spheroids. All show a central depression; this, in the case of the grains of reniform or elliptical outline, appears as a shallow, longitudinal sulcus; those of circular outline merely show a very shallow concavity limited to the near neighbourhood of the centre of the grain. Otherwise the grains are uniformly convex, and are thicker than those of pea starch. In all except the spheroidal grains there is, of course, a long and a short diameter; the former

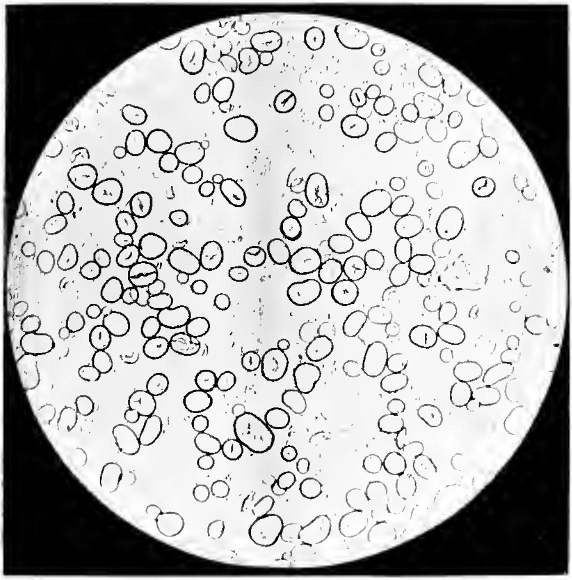

FIG. 22.—HARICOT BEAN STARCH, ×116.

in some grains may be represented by a straight line, while in others the line will be curved.*

4. By comparing Fig. 22 with Fig. 12 it will be apparent that the grains of haricot bean starch vary much more in size than do those of pea starch. This renders a reliable estimate of the average size of the grains difficult, especially as in this case one cannot ignore the small spheroidal grains, which are as typical of this starch as the large reniform grains. The largest grain in the 'field' measures $\frac{5}{100}$ mm. in the long diameter, and fully $\frac{3}{100}$ mm. in the short. The average long diameter of the elongated or reniform grains is about $\frac{7}{200}$ mm., and the short a little over $\frac{4}{200}$ mm. The diameter of the spheroidal grains varies from $\frac{3}{100}$ mm. to $\frac{1}{100}$ mm. or less. Intermediate-sized grains are common.

5. The **surface** resembles that of pea starch; while convex as a whole, there is a depression in the centre of all but the smallest grains, this depression being in the form of a shallow gutter in the elongated grains, and a shallow circular pit in the spheroidal grains.

6. The **hilum** in most cases closely resembles that of pea starch; as in the latter, it usually appears in the form of a line or groove running in the direction of the longitudinal axis, and extending about two-thirds of the length of the grain, never reaching either end of the latter. This description applies to the reniform and elliptical grains; but in the irregularly elon-

* There are, of course, many short or transverse diameters in the elongated grains of a number of the starches; but, unless otherwise stated, by 'short diameter' I mean the 'greatest transverse diameter.

gated and spheroidal grains the hilum frequently appears as a central dark spot resembling the hilum of wheat starch, but more uniformly centric than in the latter. Apart from these two types, we have frequently what may be termed aberrant forms of hilum, which appear as transverse or even oblique lines, rays, crosses, or irregular markings in the longitudinal depression. When the grain breaks, the fracture usually follows the direction of the hilum. The hilum, more or less defined, is present in the great majority of cases, but the very small grains show no hilum.

7. Beyond the hilum and the shading due to the convexity of the grain, there are no very distinctive markings on this grain. Concentric lines are difficult to make out; but there is an indication, especially in the larger specimens, of the grain being composed of concentric layers, as in the case of pea starch. These layers, in those cases where they can be observed, are arranged parallel to the periphery of the grain.

8. When examined with polarized light the appearances given are similar to those shown by pea starch (*q.v.*). The spheroidal grains show a simple rectangular black cross when the 'field' is dark.

CHAPTER XVI

CONCLUDING REMARKS

In bringing this comparatively brief, and necessarily inexhaustive, investigation to a conclusion, I am fully conscious of many inherent imperfections which, were I to pursue afresh a similar research with the additional knowledge acquired during the progress of the present work, would be in great part eliminated. While the prints themselves are almost above criticism in so far as they are reproductions whose outlines at least must be accepted as absolutely accurate, the descriptions in each case are subject to the same 'error of personal equation' noticed in the introductory part of the book. I have endeavoured to confine myself as strictly as possible to what I consider are facts admitting of absolute proof, and have avoided almost entirely mere theorizing or speculation. No attempt has been made to take up the various starches in any systematic order, and the results are given chronologically, in the order of investigation.

It may be objected to my description of the grains of any given starch that the said description, while applying to the grains in the 'fields' shown, may not apply in all particulars to the grains in other 'fields.' It is, of course, impossible in an investigation of this kind to take into

account a large number of 'fields' of each grain. What I did was, after examining ocularly many whole slides of each starch, to select that 'field' which appeared to me to show the characteristics most clearly, and to be as typical as possible of the starch under consideration. Further than this I could not go, nor did such a proceeding seem at all necessary. I am perfectly aware that the particular sample of starch has some slight effect in modifying the average size of the grains, but by repeated observations I have found that this is so slight as to be negligible in practice; the other characters described are constant, whatever the origin of the sample may be.

More important than the foregoing is the alteration of internal markings, particularly the hilum, by permeation with the medium employed for preservation of the specimen. Such alterations, when they are at all marked, are noticed where they occur; the obscuration of the hilum is most pronounced in the grains of potato and maize starches. It will be admitted, I think, that dark ground illumination is unsurpassed for showing the outline of the grains in bold relief, the interiors of the grains, from their translucency, being also dark. Unfortunately, this method is hardly applicable when objectives of less focal distance than $\frac{1}{3}$ or $\frac{1}{4}$ inch are employed.

The present investigation only clears the ground, as it were, for further work in the same direction. The changes which the various starch grains undergo on cooking, the detection of adulterations, etc., are wider questions which may profitably have separate inquiries devoted to them.

TABLE SHOWING THE LEADING MICROSCOPICAL CHARACTERS, AS FOUND IN THE PRESENT INVESTIGATION, OF THE MORE IMPORTANT STARCHES.

	Outline.	Measurement.	Surface.	Hilum.	Markings.
1. POTATO ...	Oval or elliptical	mm. $\frac{1}{25}$ in long diameter; $\frac{1}{37}$ in short diameter	Uniformly but slightly convex	Dark spot near narrow end	Concentric rings; closed, or almost closed, curves
2. RYE	Circular	$\frac{1}{40}$	Convex, spherical	Crucial or radial, central, large	Exceedingly faint complete concentric rings
3. RICE	Rectilinear and polygonal	$\frac{1}{250}$	Flat	None	None
4. OAT	Rectilinear and polygonal	$\frac{3}{500}$	Flat or slightly convex or concave	None	None
5. MAIZE	Rectilinear and polygonal	$\frac{1}{70}$	Uneven and slightly concave	Stellate or irregular, large, central	None
6. PEA	Reniform	$\frac{1}{28}$ in long diameter; $\frac{1}{40}$ in short diameter	Convex, with central longitudinal depression	Large, slit-like, longitudinal, central	Appearance of concentric rings forming closed curves
7. SAGO	Rounded; some partly angular	$\frac{7}{200}$ in long diameter; $\frac{9}{400}$ in short diameter	Uniformly and highly convex	Near large and rounded end, large, slit-like or irregular, transverse	Occasionally a few very faint, generally incomplete, concentric rings

	Outline.	Measurement.	Surface.	Hilum.	Markings.
		mm.			
8. TAPIOCA ...	Rounded; some partly angular	$\frac{1}{70}$	Uniformly convex	Slit-like, transverse, stellate, central	Like sago, but still more indistinct
9. WHEAT ...	Circular or nearly so	$\frac{1}{50}$	Convex	Dark spot, eccentric	Occasionally a few exceedingly faint concentric rings
10. BARLEY ...	Circular, lenticular	$\frac{3}{200}$	Convex	Dark spot, eccentric, seldom apparent	Very rarely, faint indication of concentric rings
11. BERMUDA ARROWROOT...	Oval	$\frac{1}{28}$ in long diameter; $\frac{1}{45}$ in short diameter	Uniformly but slightly convex	Nearer broad end, circular, crucial, transverse line or slit	Faint concentric rings in a few cases extending about two-thirds of length of grain
12. TOUS-LES-MOIS	Irregularly oval or elliptical	$\frac{7}{100}$ in long diameter; $\frac{5}{100}$ in short diameter	Uniformly but very slightly convex	Dark spot near narrow end	Concentric rings extending for less than one-third of length of grain
13. HARICOT BEAN	Reniform, elliptical, circular	$\frac{7}{200}$ in long diameter; $\frac{4}{200}$ in short diameter	Convex, with central depression	Distinct, central spot or longitudinal line or slit	Very faint appearance of concentric rings forming closed curves

It is to be noted that the details given in the foregoing table are neither absolute nor complete, and ought to be amplified by reference to the text. Much variation occurs in some cases, and the sizes can only be held to be approximately correct.

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